2012

Feeder space availability and dried distillers grains with solubles inclusion rate effects on nursery and finishing pig performance and total tract digestibility in a commercial setting

Emily Kathryn Weber
Iowa State University

Feeder space availability and dried distillers grains with solubles inclusion rate effects on nursery and finishing pig performance and total tract digestibility in a commercial setting

by

Emily Kathryn Weber

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Animal Science
Program of Study Committee:
John F. Patience, Major Professor
Kenneth J. Stalder, Major Professor
Tom J. Baas

Iowa State University

Ames, Iowa

2012

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This thesis has been the single greatest learning experience of my life and would not have been possible without the guidance, help, and support of many people. First, I would like to thank my Major Professors, Drs. John Patience and Ken Stalder, for their infinite support, guidance, and wisdom. My Master's research and thesis would never have come together without them. They always knew what to say to give me confidence in my abilities no matter what the circumstances. Their words of assurance that they would never let me fail and that mistakes were learning experiences got me through it all. I also owe a thank you to my third committee member, Dr. Tom Baas. Thank you for being a great undergraduate advisor who ultimately led to my discussions with Dr. Stalder, but also for believing in me and my success. Thank you AgFeed USA for the opportunity to complete my Master's, and become more familiar with both production research and pork production. Ron Kaptur, Zach McCracken, and Theresa Johnson thank you for all of your help weighing pigs and assisting with all of my questions. Whitney Holt, thank you for all of your help and guidance as I began my trial I could not have done it without you.

Next, I must thank my fellow Applied Swine Nutrition graduate students and undergraduate assistants: Cassie Jones, Chad Pilcher, Nestor Gutierrez, Trey Kellner, Mandy Myers, Jesus Acosta, Amanda Elsbernd, Brandy Jacobs, Monica Newman, and Alyssa Beavers. The completion of my research and thesis would not have been possible without your support but more importantly, your help. Knowing that whenever I needed assistance someone would be willing to step up made the unknowns in my trial less scary. Whenever I was having a bad day and just needed to chat I knew that I would just have to find one of you, and I would be laughing in no time. I feel extremely fortunate to be part of a team willing to help each other and want nothing but success for all. Thank you all for your help during the extremely long days! Amanda Chipman, you really are the “heartbeat of America.” I would not have been able to write a protocol, IACUC, and complete my trial and especially my lab work without you. Your positive attitude in every situation is infectious and makes things more enjoyable. Thank you for answering all my ridiculous questions and for your guidance. Thank you Shane, for your willingness to take on possibly the world’s worst job, vacuuming lots of feeders. I know it was not fun, but I was glad I did not have to do it alone. Marc and Emily Melody, thank you for taking care of my pigs every day and for ensuring that my trial was running smoothly even when I was not in the barn.

I would also like to thank the 201 Kildee group, Julie Roberts, Martha Jeffrey, Dr. Nick Gabler, Dr. Mike Persia, and the rest of the graduate students. It has been a memorable two years getting to know and interacting with all of you. I am proud to call you all friends and colleagues. Al Christian, thank you for bringing me to Iowa and giving me the opportunity to become part of the Midwest swine industry. Words cannot express how much your support, guidance, friendship, and Monday afternoon chats before swine fellows has meant to me.

Lastly, I must thank my family. My dad and sisters (Kelli, Kristin, and Erin) have been absolutely irreplaceable throughout my time in graduate school. Their love, support, calming influence, and humor was always the best form of stress release. Thank you for everything and for always knowing the right thing to say to calm my fears.

ABSTRACT

The study objectives were to determine the effect of feeder space allowance on nursery pig performance, and to determine the effect of the same feeder space allowance in combination with varying DDGS inclusion levels on finishing pig performance, carcass characteristics, and nutrient digestibility. These studies were carried out on the same group of pigs within a commercial wean-finish system. For the nursery phase, a completely randomized design was used to compare 3 feeder space allowance treatments (2.1, 2.5, 2.9 cm/pig). Pigs (n = 3,720) were randomly allotted to same sex pens (10 feeders /treatment) of 62 pigs/pen. Thirty 7-hole double sided feeders were utilized in the study. Differing linear feeder space treatments were established by blocking off feeder sections for both studies. All pigs had equal floor space ($0.85m^2$/pig). In the grow-finish phase, a total of 60 pens (n = 1,860 pigs) were utilized in a 2 x 3 factorial design with 3 feeder space allowances (4.1, 4.9, or 5.7 cm/pig) and 2 dietary DDGS treatments (D30 and D60). Fecal and diet samples were collected and analyzed to determine apparent total tract digestibility % (ATTD %) and energy content. In the nursery portion of the trial, there was no effect of feeder space treatment on ADG, ADFI, or feed efficiency ($P > 0.05$) from weaning to d 56 post-weaning or during any weigh period. In the grow-finish portion of the trial, feeder space allowance and DDGS inclusion level did not affect ADG, ADFI, or feed efficiency ($P > 0.05$) from d 57 post-weaning to market. Pigs that were fed the D30 diet had a heavier HCW, higher percent yield, and greater loin depth than those on the D60 diet ($P < 0.05$). There were no backfat depth treatment differences ($P > 0.05$). Pigs on the D30 treatment had greater ($P < 0.05$) ATTD of DM and GE for both collection periods compared to those on the D60 treatment. Energy content of the diet was greater for the D30 diet ($P < 0.05$) for period 1, but not for period 2. In summary, feeder space allowance did not impact pig performance overall during the nursery and grow-finish phase. Inclusion of DDGS at a higher level will decrease ADFI, but not ADG or efficiency when diets are isocaloric. Higher DDGS inclusion will impact HCW and percent yield, due to increased intestinal weight providing a greater proportion of weight for pigs fed high inclusions of DDGS. DM and energy digestibility was greater for the D30 diet; however energy content of the diets varied between fecal collection periods.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

There has been little research on the effects of feeder space allowance per pig and grower-finisher pig diets with an aggressive inclusion of dried distillers grains with solubles (DDGS) in a commercial setting. Additionally, the digestibility of energy in diets with DDGS inclusion above 30% is generally unknown. With the current emphasis on decreasing feed costs without compromising performance, these issues are becoming increasingly important. Feeder space allowance requirements for nursery or grower-finisher pigs have been broadly defined, but have not been studied to the extent where the industry fully understands them. Feeder space is defined as the amount of available space in a feed trough per pig or per some defined number of pigs, and ultimately depends on how long the feeder is and how many pigs are typically housed in a given pen. The ideal feeder space per pig may be limited due to industry trends to increase stocking density, without increasing feeder allowance. The purpose of this thesis is to summarize previous research regarding these topics, and to present current research findings regarding feeder space allowance and DDGS inclusion in pig diets.

The objective of this experiment was to determine the effect of feeder space allowance during the nursery phase on performance of pigs that were double stocked (twice as many pigs were placed in pens at weaning), and secondly, to determine the impact of feeder space allowance and DDGS inclusion level on pig performance and nutrient digestibility during the growing-finishing phase.

Thesis Organization:

This thesis is written in the journal paper format permitted by the Graduate College at Iowa State University. It contains a review of previous literature pertaining to the impact of feeder space allowance and DDGS inclusion level on pig performance and apparent total tract digestibility of DM and energy. Additionally, it includes one manuscript to be submitted the *Journal of Animal Science*, a general discussion, and an appendix. The appendix outlines how feed delivery was recorded and calculated using the error of the system. A general discussion concludes the thesis, with overall results and suggestions for future research. All references are listed in the "Literature Cited" section within each chapter. Chapter 2 is formatted according to the *Journal of Animal Science* requirements.

Literature Review:

Feeder Space

Definition of Feeder Space:

Providing animals with access to adequate, but not excessive, feeder space is an essential constituent of successful barn management in terms of pig performance and financial returns. However, research on feeder space allowance is limited (Brumm and Gonyou, 2001). Feeder space is defined as the amount of available space in a feed trough per pig or per a defined number of pigs in a pen, and ultimately depends on the length of a feed trough. Feeder space allowance is determined by taking the feeder trough length divided by the number of pigs in the pen or a pre-defined number of pigs per feeder space (i.e. 10 pigs per feeder space). Traditionally, pork producers have been advised to provide 1 feeding space per 4 pigs in the nursery phase, and 1 feeding space per 4 or 5 pigs in the finishing phase (MWPS, 1991); however, no minimum feeder space required expressed in linear length is available.

Currently, there is little published research in scientific journals on feeder space allowance that do not vary in stocking density. For this reason a majority of the data discussed in this literature review are stocking density trials which discuss feeder space allowance. However, this area of research is important in today's industry as input costs and market weights rise.

Although the effects of feeder space allowance on pig performance have not been extensively studied, there has been research investigating the typical eating behavior of pigs. Understanding the pig's eating behavior is important to understanding optimal feeder space allowance. Turner et al. (2002) reported the percentage of group members observed eating and queuing for access to feeders was not changed during the day or night when either 3.25 cm or 4.25 cm per pig feeder space allowance was offered. However, pigs were observed to spend a longer duration feeding per day when offered the lower space allowance (Turner et al., 2002). Feeder aggression and competition are also a concern when feeder space is limited. Spoolder et al. (1999) reported a lower incidence of feeder aggression when pigs were offered 2 vs. 1 feeder space per 20 pigs, and when housed in either groups of 20 or 80. He classified feeder aggression as pushes or knocks from pigs that were trying to displace other pigs and gain access to a feed space. Morrow and Walker (1994) reported increased activity levels that may be related to an increased waiting time at feeders, particularly in late finishing. Pigs' aggressive activities at the feeder may cause them to use energy which the pig could ultimately use for BW gain. The biggest concern with competition and restricted space at the feeder is its impact on increased activity and energy expenditure will increase social disruption and impact pig performance.

Impact of Feeder Space on Pig Performance:

Insufficient feeder trough space is likely to negatively impact pig performance. The performance variables which will most likely be impacted are BW, gain, feed intake and efficiency. Currently, there are limited and inconsistent scientific data on how growth performance is impacted by feeder space allowance. It has been thought that feeder trough space would only become limiting in the late finisher phase, but research has shown that there can be an effect that is measurable as early as the nursery phase. In early research by Lindeman (1987) when weaned pigs were offered from 2 to 12 sections (15.2 cm sections) of feeder trough space with 12 or fewer pigs in the pen, there were no differences in pig performance across feeder space treatments. More current research has found that for the first 6 wks post-weaning there were no performance differences for pigs offered 2 vs. 4 cm feeder trough space (Wolter et al., 2002). However, in the same study from wk 6 to 8 post-weaning, pigs with 4 cm/pig feeder trough space had a greater ADG, but ADFI and gain:feed did not differ. Additionally, at wk 8 post-weaning, those pigs provided with 4 cm feeder trough space/pig had a heavier BW. Wolter et al. (2003) reported no ADG or BW differences when pigs were offered 2 or 4 cm/pig feeder trough space from post-weaning to either 12 or 14 wks post-weaning (5.5 to 57 kg). During the same study pigs with 2 cm/pig feeder trough space had decreased ADFI. This reduction in ADFI may have been due to feed access and feeder adjustment. It has been concluded that feeders which allow the pig easier access to feed, including optimal feeder gap adjustment, increase the number of pigs which can eat from a given feeding space (Smith et al., 2004). This study also shows no impact of feeder space allowance during the early grow-finish phase.

Results examining the effects of feeder space during the finishing phase are more consistent. Gonyou and Lou (2000) reported that there were no differences overall for any performance variable in a 12 wk study (25 to 106 kg) when pens of 12 pigs were offered either a single or multi-space feeder. Increased feeder space allowance did not improve gain or efficiency from findings reported by Morrow and Walker (1994), where pens of 20 pigs had access to either 1 or 2 identical feeders. Feed disappearance was slightly increased when pigs were offered greater access to feeders, but this was possibly a feed wastage issue. Turner et al. (2002) found that overall ADG was not significantly affected by offering pens of 20 or 80 pigs either 3.25 cm or 4.25 cm of feeder space per pig from 29-56 kg. However, during the last 3 wks (41 to 56 kg), ADG significantly decreased when less feeding space was available. This suggests that as pigs grow and shoulder width increases, fewer pigs are able to eat at one time. Thus, when designing feeders it is important to consider how both nursery and grower-finisher pigs will utilize the feeding space. Feed intake significantly decreased for the pigs that had access to 3.25 cm per pig when compared to those pigs having 4.25 cm per pig. The varying results in feed intake could be attributed to many factors such as feeder adjustment and altered eating patterns. According to Brumm and Gonyou (2001), pigs will alter their typical eating patterns to adapt to their environment, such as restricted feeder-trough space.

Dried Distillers Grains with Solubles:

Research on distillers dried grains with solubles (DDGS) has been conducted for over 50 years, with the work evolving as modern ethanol production became a larger player in the corn market (Stein and Shurson, 2009). This subsequent reduced availability of corn forced pork producers and the feed industry to begin to understand how to utilize the by-products of fermentation, such as DDGS, and the impact that feeding them would have on pig performance. In 2011, there were approximately 209 ethanol bio-refineries located in 29 states, which produced an estimated 13.9 billion gallons of ethanol. This required approximately 5 billion bushels of corn, which yielded approximately 35.7 million metric tons of distiller's grains to be used as livestock feed (Renewable Fuels Association, 2012). The pork industry utilized an estimated 11% of the available distiller's grains (Renewable Fuels Association, 2012).

Impact of Dried Distillers Grains with Solubles on Pig Performance:

To date most pig research has focused on determining the maximum DDGS level that can be included in the diet without impacting pig performance and barn throughput. However, most published research has not investigated the inclusion of DDGS in diets greater than 50%; thus the maximum amount of distillers which can be added to a diet fed to nursery or grower-finisher pigs without impacting performance is unknown. It has been reported with some consistency that inclusion of up to 30% DDGS in the diet will not impact ADG or ADFI (Cook et al., 2005; DeDecker et al., 2005; Gaines et al., 2007a). However, there has been some disagreement on the effects of varying DDGS levels on gain:feed. Cook et al. (2005) reported no gain:feed difference when feeding isocaloric diets containing 0, 10, 20, or 30% DDGS. Gaines et al. (2007a) reported a decrease in gain:feed when 30% DDGS was included in the diet, and DeDecker et al. (2005) and Xu et al. (2007a) reported an improvement in gain:feed with the same inclusion. When growth rate remains the same, and feed conversion varies, it generally, although not always, means that the energy content of the test ingredient was over- or under-estimated.

It has also been reported that including 20 or 30% DDGS will decrease ADG, ADFI, or G:F (Whitney et al., 2006; Linneen et al., 2008; Xu et al., 2010). No studies have been published that report a decrease in all performance variables when increasing levels of DDGS were added to the diet. The differences that have been observed for gain, feed intake, and efficiency could be attributed to variability or quality differences from the DDGS that were used in the experiments. There could have been differences in energy concentration, nutrient digestibility, or palatability (Stein and Shurson, 2009); however, the latter is difficult to measure. Work by Hastad et al. (2004) reported decreased ADFI for DDGS diets when a corn-soybean diet that did not contain DDGS was offered in the same pen. These data suggest that when pigs have access to either a typical corn-soybean meal diet or a diet containing DDGS, they will choose the corn-soybean meal diet. Additionally, ADFI decreased as the amount of DDGS in the diets increased in this study (Hastad et al., 2004). Discrepancies in final BW have also been reported. Cook et al. (2005) reported no differences in final BW with increasing levels of DDGS, whereas, Hinson et al. (2007) reported decreased BW as DDGS inclusion increased. Stein (2007) reported that some producers have been successful feeding diets that include 35% DDGS. However, more research needs to be done in the area concerning diets with inclusion of DDGS greater than 50%.

Impact of Distillers Dried Grains on Carcass Characteristics:

It has been reported that as the DDGS level in the diet increases, final BW and carcass weight will decrease (Whitney et al., 2006; Hinson et al., 2007). However, lower carcass weights may not be solely due to decreased final BW; gut fill may also play a role. Asmus et al. (2011) reported that as the NDF level in the diet increased, both full and stripped intestine weights increased. Internal organs and the head are not weighed as part of the hot carcass weight in the United States. Therefore, even if no difference in final BW occurs with increasing DDGS inclusion level, there is potential for a difference in carcass weight. Other researchers have reported no difference in carcass weight with increasing levels of DDGS (Gaines et al., 2007a). It has been consistently reported that as DDGS in the diet increases, carcass yield will decrease (Cook et al., 2005; Whitney et al., 2006; Gaines et al., 2007a; Hinson et al., 2007; Xu et al., 2010). When examining the impact of DDGS on backfat and loin depth, previous results have varied. Cook et al. (2005), Whitney et al. (2006), and Gaines et al. (2007a) reported no differences for backfat depth as DDGS in the diet increased; however a decrease in loin depth was reported (Whitney et al., 2005; Gaines et al., 2007a). There have been differences in backfat depth reported when ADFI decreased, therefore reducing daily energy intake due to DDGS inclusion. This reduction in backfat was caused by the pigs having less energy available for fat synthesis (Xu et al., 2007). These differences could be explained by different genetics and market weights for each trial.

In addition to understanding the individual impact of both feeder space allowance and DDGS inclusion rate in pig diets, the interaction between the 2 effects has not been investigated. It has been hypothesized that when pigs are fed greater quantities of DDGS they will eat slower and visit the feeder more frequently. These effects could possibly be due to gut fill or diet palatability issues, as described earlier. If this is the case, then feeders would have to be able to handle a larger pig load as pork producers continue to include DDGS in the diet. Additionally, feeders are an expensive input and it could potentially cost producers a large amount of money to purchase longer feeders. However, if this is not the case, then producers could potentially feed greater amounts of DDGS without impacting pig performance and without having to purchase new feeders.

Apparent Total Tract Digestibility of Dried Distillers Grains with Solubles:

During alcohol production from corn most of the starch is removed and converted into alcohol and carbon dioxide, resulting in increased remaining nutrient concentration (Spiehs et al., 2002). These concentrated nutrients include dietary fiber (ADF, NDF, and TDF) which is not readily digestible by the monogastric gastrointestinal tract. Spiehs et al. (2002) reported average nutrient levels for DM (88.9%), CP (30.2%), fat (10.9%), ADF (16.2%), and NDF (42.1%) for DDGS from 10 different ethanol sources. He also reported that the nutrient composition of DDGS will vary depending on the ratio of grains and solubles that are combined. This possible variation in DDGS is something that must be considered when determining the appropriate amount to include in the diet. Not only is there variation between bio-refineries, but batch variation within a bio-refinery also exists. These differences can be attributed to year to year corn variation, geographic location, fertilization, and growing conditions (Spiehs et al., 2002; Pedersen et al., 2007). Variation in DDGS can lead to differences in digestibility of energy as shown by (Stein et al., 2006; Pedersen et al., 2007; and Stein et al., 2009).

Inclusion of DDGS in the diet for growing pigs will affect DM and energy digestibility. Urriola and Stein (2010) found that pigs fed a diet with 30% DDGS had a lower DM and GE ATTD compared to pigs that were fed a control corn-soybean meal diet. Additionally, Widyaratne and Zijlstra (2007) reported greater total tract digestibility of energy for pigs fed a wheat-based control diet compared to pigs fed diets which included corn and DDGS. That same study reported a greater DM excretion from the pigs fed the corn-based DDGS diets. Dégen et al. (2009) reported that energy digestibility decreased as fiber level increased in a study where wheat bran was fed to pigs. This reduction is likely due to the wheat fiber composition which is primarily insoluble, much like the fiber composition found in corn DDGS. Additionally, in other work by Stein et al. (2006), it was reported those diets containing DDGS had a lower DM and energy ATTD when compared to a corn-based diet.

In diets for pigs containing DDGS, digestibility is likely reduced due to the increased fiber content (ADF, NDF, and TDF). Dietary fiber, reflected in ADF and NDF assays, has a lower digestibility than starch when fed to pigs (Stein and Bohlke, 2007). Corn fiber is mainly insoluble and composed of cellulose and arabinoxylans (Bach Knudsen, 1997; Guillon et al., 2007). Thus, the chemical characteristics restrict the fiber utilization in the diet due to limited retention time and fermentation in the hindgut. Fiber will become more available for digestion as the passage rate slows (Noblet and Le Goff, 2001). Although not scientifically confirmed, Noblet and Le Goff (2001) suggested hindgut size, as a proportion of live weight or relative to feed intake, increases with BW. This results in a slower digesta passage rate and prolonged time for fermentation in the ileum. Additionally, there could be possible changes in the microbial population composition found in the hindgut, which could contribute to increased fiber digestibility (Noblet and Le Goff, 2001).

The DE and ME values which have been reported for DDGS are similar to that of corn. When testing 10 DDGS sources and comparing them to a corn-soybean meal control diet, Pedersen et al. (2007) reported similar DE and ME values for the control diet (4,088 and 3,989 kcal/kg of DM, respectively), and the diets with DDGS (4,140 and 3,897 kcal/kg of DM, respectively). However, this study reported DE and ME differences between DDGS sources. The DE and ME variation between DDGS sources shown by Pedersen et al. (2007) suggests that if nutrient specifications used to formulate diets do not directly reflect the composition of the DDGS used, the formulated DE and ME of the diet could differ from the actual energy in the diet. In a study conducted to determine DDGS variation from 10 different ethanol bio-refineries, Spiehs et al. (2002) reported an average DE (3990 kcal/g) and ME (3749 kcal/g) from the DDGS samples evaluated. Additionally, this study reported DE and ME values did not differ from NRC (1998) values for corn grain. Based on these results, adding DDGS to diets fed to pigs will not change the DE and ME of the diet. However, due to energy digestibility differences between the 2 ingredients, performance may be impacted as discussed previously. To date, DDGS NE values have not been determined (Stein and Shurson, 2009). Dégen et al. (2009) suggested that the DE, ME, and even NE are based on the digestible nutrient content which are present in the diet, however, this may fail to give an accurate digestible nutrient and energy content of the mixed feed.

Conclusion

Research results have been inconsistent when trying to define the optimal feeder space requirement per pig to maintain performance. However, this type of research is necessary as input costs continue to rise and pigs are marketed at heavier weights. It is important to remember that care must be taken when applying feeder space allowance results to commercial systems that may differ from those found in the research environment used in the present study. Gonyou and Lou (2000) suggested that diet form, feeder design, and pig BW may impact the effect of feeder-trough space allowance on pig performance. There has been extensive research completed to determine the effect of diets containing up to 30% DDGS when fed to grow-finish pigs with consistent results. However, there are limited published data on how pig performance is affected when DDGS are added to the diets in excess of 50%. As the ethanol industry continues to process more of the corn crop each year, utilizing large quantities of DDGS in pig diets may be inevitable. The issue with including large proportions of DDGS in the diet is fiber concentration. Insoluble dietary fiber is not readily digested by pigs, thus dietary nutrient digestibility is decreased in the diet. When compared to a corn-soybean meal diet, pigs eating a diet containing DDGS have lower energy and DM digestibility. Although feeding DDGS in pig diets may not decrease performance, pigs may not be able to utilize all of the nutrients that are present in the feed.

Literature Cited

Asmus, M. D., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz, R. D. Goodband, and T.A. Houser. 2011. Effects of lowering dietary NDF levels prior to marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. Kansas State University Swine Day 2011. Report of Progress 1056: 202-215.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Tech. 67:319-338.

Brumm, M. C., and H. W. Gonyou. 2001. Effects of facility design on behavior and feed and water intake. In: A.J. Lewis and L.L. Southern (ed.) Swine Nutrition, 2nd ed. Pp. 499-518. CRC Press, Boca Raton, Fl.

Cook, D., N. Paton, and M. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83 (Suppl. 1):335. (Abstr.)

DeDecker, J. M., M. Ellis, B. F. Wolter, J. Spencer, D. M. Webel, C. R. Bertlsen, and B. A. Peterson. 2005. Effects of dietary level of distiller's dried grains with solubles and fat on the growth performance of growing pigs. J. Anim. Sci. 83 (Suppl. 2):79. (Abstr.)

Dégen, L., V. Halas, J. Tossenberger, C. Szabo, and L. Babinszky. 2009. The impact of dietary fiber and fat levels on total tract digestibility of energy and nutrients in growing pigs and its consequence for diet formulation. Acta. Agr. Scan. A-AN. 59:150-160.

Gaines, A. M., G. I. Petersen, J. D. Spencer, and N. R. Augspurger. 2007a. Use of corn distillers dried grains with solubles (DDGS) in finishing pigs. J. Anim. Sci. 85(Suppl. 2):96. (Abstr.)

Gonyou, H. W., and Z. Lou. 2000. Effects of eating space and availability of water in feeders on productivity and eating behavior of grower/finisher pigs. J. Anim. Sci. 78:865-870.

Guillon, F., L. Saulnier, P. Robert, J. F. Thibault, and M. Champ. 2007. Chemical structure and function of cell walls through cereal grains and vegetable samples. Pages 31-64 in Dietary Fibre Components and Functions. H. Salovaara, F. Gates, and M. Tenkanen, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.

Hastad, C. W., J. L. Nelssen, R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and N. Z. Frantz. 2005. Effect of dried distillers grains with solubles on feed preference in growing pigs. J. Anim. Sci. 83(Suppl. 2):73. (Abstr.)

Hinson, R., G. Allee, G. Grinstead, B. Corrigan, and J. Less. 2007. Effect of amino acid program (Low vs. High) and dried distillers grains with solubles (DDGS) prior to slaughter in finishing pigs. J. Anim. Sci. 85 (Suppl. 1):437. (Abstr.)

Lindemann, M. D., E. T. Kornegay, J. B. Meldrum, G. Schurig, and F. C. Gwazdauskas. 1987. The effect of feeder space allowance on weaned pig performance. J. Anim. Sci. 64:8-14.

Linneen, S. K., J. M. DeRouchey, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J .L. Nelssen. 2008. Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579-1587.

Morrow, A. T. S., and N. Walker. 1994. Effects of number and siting of single-space feeders on performance and feeding-behavior of growing pigs. J. Agr. Sci. 122:465-470

MWPS. 1991. Swine housing and equipment handbook. Midwest Service Plan MWPS-8, 4th ed., 3rd printing, Ames, IA.

Noblet, J., and G. Le Goff. 2001. Effect of dietary fibre on the energy value of feeds for pigs. Anim. Feed. Sci. Tech. 90:35-52.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Renewable Fuels Association. 2012. Renewable fuels standard. Accessed July 14, 2012. http://ethanolrfa.3cdn.net/d4ad995ffb7ae8fbfe_1vm62ypzd.pdf.

Smith, L. F., A. D. Beaulieu, J. F. Patience, H. W. Gonyou, and R. D. Boyd. 2004. The impact of feeder adjustment and group size-floor space allowance on the performance of nursery pigs. J. Swine Health Prod.:111-118.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci 80:2639-2645.

Spoolder, H. A. M., S. A. Edwards, and S. Corning. 1999. Effects of group size and feeder space allowance on welfare in finishing pigs. Anim. Sci. 69:481-489.

Stein, H. H. 2007. Distillers dried grains with solubles (DDGS) in diets fed to swine. Swine Focus No. 001. Univ. of Illinois, Urbana-Champaign.

Stein, H. H., S. P. Connot, and C. Pedersen. 2009. Energy and Nutrient Digestibility in Four Sources of Distillers Dried Grains with Solubles Produced from Corn Grown within a Narrow Geographical Area and Fed to Growing Pigs. Asian Austral. J. Anim. 22:1016-1025.

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 84:853-860.

Stein, H. H. and R. A. Bohlke. 2007. The effects of thermal treatment of field peas (*Pisum sativum L.*) on nutrient and energy digestibility of growing pigs. J. Anim. Sci. 81:2639-2645.

Stein, H. H., and G. C. Shurson. 2009. BOARD-INVITED REVIEW: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Turner, S. P., M. Dahlgren, D. S. Arey, and S. A. Edwards. 2002. Effect of social group size and initial live weight on feeder space requirement of growing pigs given food ad libitum. Anim. Sci. 75:75-83.

Urriola, P. E., and H. H. Stein. 2010. Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. J. Anim. Sci. 88:1454-1462.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Widyaratne, G. R., and R. T. Zijlstra. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 87:103-114.

Wolter, B. F., M. Ellis, B. P. Corrigan, J. M. DeDecker, S. E. Curtis, E. N. Parr, and D. M. Webel. 2003. Effect of restricted postweaning growth resulting from reduced floor and feeder-trough space on pig growth performance to slaughter weight in a wean-to-finish production system. J. Anim. Sci. 81:836-842.

Wolter, B. F., M. Ellis, S. E. Curtis, E. N. Parr, and A. M. Webel. 2002. Effects of feeder-trough space and variation in body weight within a pen of pigs on performance in a wean-to-finish production system. J. Anim. Sci. 80:2241-2246.

Xu, G., S. K. Baidoo, L. J. Johnson, J. E. Cannon, and G. C. Shurson. 2007a. Effects of adding Increasing levels of corn dried distillers grains with solubles (DDGS) to corn-soybean meal diets on growth performance and pork quality of growing-finishing pigs. J. Anim. Sci. 85(Suppl. 2):76. (Abstr.)

Xu, G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon, and G. C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower- finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-1410.

IMPACT OF FEEDER SPACE AVAILABILITY AND DRIED DISTILLERS GRAINS WITH SOLUBLES INCLUSION RATES ON NURSERY AND FINISHING PIG PERFORMANCE AND TOTAL TRACT DIGESTIBILITY IN A COMMERCIAL SETTING

A paper to be submitted to the *Journal of Animal Science*

Emily Weber, Ken Stalder, and John Patience

Abstract

The study objectives were to determine the effect of feeder space allowance during the nursery phase on performance of pigs that were double stocked, and secondly, to determine the impact of feeder space allowance and DDGS inclusion level on pig performance and nutrient digestibility during the growing-finishing phase. These studies were carried out on the same group of pigs within a commercial wean-finish system. For the nursery phase, a completely randomized design was used to compare 3 feeder space allowance treatments (2.1, 2.5, 2.9 cm/pig). Pigs (n = 3,720) were randomly allotted to same sex pens (10 feeders/ treatment) of 62 pigs/pen. Thirty 7-hole double sided feeders were utilized in the study. Differing linear feeder space treatments were established by blocking off sections for both studies. All pigs had equal floor space ($0.85 m^2$/pig). In the grow-finish phase, a total of 60 pens (n = 1,860 pigs) were utilized in a 2 x 3 factorial design with 3 feeder space allowances (4.1, 4.9, or 5.7 cm/pig) and 2 dietary DDGS treatments (D30 or

D60). Fecal and diet samples were collected and analyzed to determine apparent total tract digestibility (ATTD %) and energy content. In the nursery portion of the trial, there was no effect of feeder space treatment on ADG, ADFI, or feed efficiency ($P > 0.05$) from weaning to d 56 post-weaning or during any weigh period. In the grow-finish portion of the trial, feeder space allowance and DDGS inclusion level did not affect ADG, ADFI, or feed efficiency ($P > 0.05$) from d 57 post-weaning to market. Pigs fed the D30 diet had greater HCW, percent yield, and loin depth than those on the D60 diet ($P < 0.05$). There were no backfat depth treatment differences ($P > 0.05$). Pigs fed D30 DDGS treatment had greater ($P < 0.05$) ATTD for DM and GE for both collection periods compared to those on the D60 DDGS treatment. In summary, feeder space allowance did not impact pig performance overall during the nursery and grow-finish phase. Inclusion of DDGS at a higher level will decrease ADFI, but not ADG or efficiency when diets are isocaloric. DDGS inclusion does impact HCW and percent yield, due to increased intestinal weight for pigs fed diets containing relatively high DDGS inclusion rates. Digestibility of DM and energy was greater for the low DDGS diet; however dietary energy content varied between fecal collection periods.

Keywords: feeder space, DDGS, performance, digestibility, pigs

Introduction

Providing animals with access to adequate, but not excessive, feeder space is an essential constituent of successful barn management. However, research on the impact of feeder space allowance is limited (Brumm and Gonyou, 2001). Wolter et al. (2003) reported no impact on performance when pigs had access to 2 or 4 cm feeder-trough space for up to 14 weeks post-weaning. Traditionally, pork producers have been advised to provide 1 feeding space per 4 pigs in the nursery phase, and 1 feeding space per 4 or 5 pigs for the grow-finish phase of pork production (MWPS, 1991); however, no minimum feeder space allowance expressed in linear length is available in the scientific literature or swine management handbooks.

Additionally, there are varying recommendations on the optimal DDGS inclusion rates that should be fed to pigs from weaning to market. A number of authors (Cook et al., 2005; DeDecker et al., 2005; Whitney et al., 2006; Gaines et al., 2007a) suggest that DDGS can be fed at dietary concentrations up to 30% and serve as a satisfactory energy and protein source in growing-finishing pig diets.

During the fermentation process to produce ethanol, most of the starch in corn is removed, and as a result DDGS contain approximately 35% insoluble and 6% soluble dietary fiber. Increased fiber content, especially when fed at aggressive levels, will impact nutrient digestibility in diets fed to grower-finisher pigs (Stein and Shurson, 2009). However, it has been speculated that feeding diets with relatively high DDGS inclusion rates may reduce the pigs' eating speed, thus putting more pressure on feeder space allowances.

Therefore, the objective of this experiment was to determine the effect of feeder space allowance during the nursery phase on performance of pigs that were double stocked, and secondly, to determine the impact of feeder space allowance and DDGS inclusion level on pig performance and nutrient digestibility during the growing-finishing phase.

Materials and Methods

All procedures used in this experiment were approved by the Iowa State University Institutional Care and Use Committee (#6-11-7165-S).

Animals, Housing, and Management. A total of 3,720 crossbred pigs (Large White x Landrace female x PIC terminal sire; PIC, Hendersonville, TN) weaned at approximately 16 d of age and weighing 5.67 (±.12) kg were allotted to treatments 72 hours after weaning. Pigs were selected visually to be included in the experiment based on estimated weight and gender. Initially, pigs were placed in groups of 180 animals and then divided into 3 weight categories: small, medium, and heavy. At the time of allotment all pigs farrowed from gilt litters, which were signified with a notch in their ear, were separated and placed, put in off-test pens, and were not utilized in the study. Pigs were provided *ad libitum* access to feed and water between weaning and allotment. Half of the pigs in each weight category were randomly selected and tagged with a colored ear tag (Destron Fearing™ Duflex Hog Max®, QC Supply LLC., Schulyer, NE) using 1 color per weight category; the eartag indicated which pigs would remain at the end of the nursery phase because double stocking procedures were employed during this period. Additionally, this process ensured that pigs were randomly selected for inclusion in the grow-finish phase of the experiment. Twenty small, 22 medium, and 20 heavy pigs (half tagged and half not tagged) were randomly selected for placement in each experimental pen by sex. During the nursery phase, when an ear tagged pig dies or is removed from trial a pig from the same pen of similar size and weight will be ear tagged to replace the removed pig

During the nursery period, pens were double stocked (62 barrows or gilts per pen and 124 pigs per feeder), meaning that twice as many pigs were placed in pens at weaning; half of the pigs were moved to another grow-finish facility at the end of the nursery phase. At d 56 post-weaning, or at the end of the nursery phase, the non-tagged pigs were removed from the barn to an offsite grow-finish barn, leaving a total of 1,860 pigs on test for the growing and finishing phase of the study (31 barrows or gilts per pen and 62 pigs per feeder). Pigs remained on test from d 57 post-weaning until marketing at approximately 122 kg.

Feeders were located in the pen partition and thus supplied feed to 2 adjacent pens. A total of 30 double-sided feeders (12 gilt, 12 barrow, and 6 gilt and barrow), providing feed to 60 pens in total, were used in this experiment. Pens housing pigs of the same sex were then randomly assigned to 1 of 3 feeder space treatments defined below.

Pigs were housed in a double wide (2 identical rooms under one roof; 30.8 x 59.7 m), tunnel-ventilated wean-finish barn, contracted by AgFeed USA, LLC. in central Iowa. The 2 rooms in the barn were identical with fully slatted floors, metal pen divisions, and PVC front gates. Pen dimensions were either 5.87 x 2.74 m or 4.78 x 3.35 m; corner pens against the outside wall on the curtain end were .61 m wider than all other pens. All pens provided the same floor space per pig through the use of a moveable PVC gate in the back of the pen. For the first 56 d post-weaning, pigs were provided 0.26 m^2 of floor space each and from d 57 post-weaning to market, they were provided with 0.52 m^2 floor space. Barn ventilation including fans, inlets, and heaters were controlled by an integrated system (Expert VT 110, Automated Production Systems, Assumption, IL). For the first 2 wks post-weaning, supplemental heat was provided using propane brooders.

Experimental Design, Diets, and Feeder Space Allowance. Each pair of pens was equipped with a 7 space (trough length=177.8 cm.), stainless steel dry feeder (Quick Adjust Style R, Smidley, Britt, IA) and 4 nipple waterers per pen. Feeders were modified with a galvanized steel cover to adjust feeder space and to provide feeder space treatments (See Figure 1). Covers were placed and secured on feeders by placing a threaded rod through the center and securing on either end with a lock washer and acorn nut. Feeder spaces were covered such that the same individual feeder spaces were inaccessible for all feeders on the same treatment. Feeders were adjusted so one-third to one-half of the feed trough was covered with feed (Smith et al., 2004). Adjustments ensured minimum feed wastage, without restricting feed intake and thus compromising pig welfare or growth performance.

During the nursery phase, from d 3 post-weaning to d 56 post-weaning the experiment was designed as a randomized complete block, with 10 feeders (pen pairs) per treatment and 620 pigs per treatment. Treatments consisted of 3 feeder space allowances (2.1 cm, 2.5 cm, and 2.9 cm per pig).

In the grow-finish study, the same pens were used in a 2 x 3 factorial design with 3 feeder space allowances (4.1 cm, 4.9 cm, and 5.7 cm per pig) and 2 dietary treatments (D30 and D60 DDGS). Pig performance from d 57 post-weaning to market was evaluated on split sex pen groups. There were 31 pigs per pen with 5 replicates per treatment.

Pigs were fed according to an 8 phase, dietary feed budget regimen, such that each pair of pens received an equal amount of each phase of diet. For the first 15 days, all pigs were provided the same quantity of the phase 1 and 2 pelleted starter diets (JBS United Feeds Inc., Sheridan, IN). Following the starter diets, experimental diets were provided in meal form. Dietary treatments were formulated to meet or exceed NRC (1998) requirements (Table 1) and were isocaloric within phase. Diets were made isocaloric with the addition of Choice White Grease (CWG). For phases 5, 6, and 7, diets contained either 30% (D30) or 60% (D60) DDGS. Inclusion of DDGS in the diets was at the expense of corn. Pigs were fed diets containing these DDGS inclusion rates for approximately 69 d during the grow-finish phase. On approximately d 126 post-weaning, DDGS levels were reduced to 26% (D30 treatment) or 30% (D60 treatment). This was a DDGS step down program before marketing in order to improve yield and reduce fat quality concerns. Pigs consumed these diets for approximately the last 33 d of the finishing phase.

Data Collection. One pen per feeder (n=30) was weighed (Load cells and scale readout Tru Test Limited, Wellington Auckland, New Zealand; 0 ± 1.0 kg) individually at the beginning and first pull in the grow-finish phase to determine BW coefficient of variation. Pens of 62 pigs were weighed (Load cells, Artech Industries Inc., Riverside, CA; scale readout, Rice Lake Weighing Systems, Rice Lake, WI; 0 ± 1.0 kg) every 2 wks for the first 56 d post-weaning, and pens of 31 pigs were weighed at each diet phase change from d 57 to the end of the study. Pen weights within feeder were combined to calculate growth performance, as feeder was the experimental unit. Feed usage was determined for the same time periods as BW. If a pig was removed from the study due to death, injury, or illness, the date of removal and the pigs BW was recorded.

Complete pens of pigs were marketed on d 153, 157, or 159 post-weaning when the mean pen BW was 122.6 kg ± 4.5 kg. Carcass measurements, including HCW, backfat and loin depth were collected at the harvest facility (Fat-O-Meter, SFK Technology, Copenhagen, Denmark). Pigs were marketed by feeder so that confounding of feeder space and DDGS diet treatment by market date was avoided.

Fecal grab samples were collected daily during a 2-d collection period for each experimental diet during the midpoint of phase 6 (d 92-94**)** and phase 7 (d 115-118) of the 159-d growth experiment. Fecal and feed samples were collected in the barn and then stored at -20°C, homogenized, lyophilized (Model 10-100, Virtis Co. Ltd., Gardiner, NY) to a constant weight, and ground through a 1.0 mm screen (Wiley Mill 3379-K35, Thomas Scientific, Swedesboro, NJ).

Dry matter was determined on feed and fecal samples which were dried at 105°C to a constant weight. Acid detergent fiber was determined in triplicate on feed using an Ankom Fiber Analyzer per manufacturer's instructions (Model 2000, Ankom Technology, Macedon, NY). Fat content in the feed was estimated using ether extraction according to method 920.39 (AOAC , 2007). Gross energy was determined using a bomb calorimeter (Model 6200, Parr Instrument, Moline, IL). Benzoic acid (6,318 kcal/g) was the standard used to calibrate the instrument (6,318 ± 18 kcal/kg, required; 6,314.5 ± 6.4 kcal/kg determined). Nitrogen content was determined using a TruMac®N Nitrogen Analyzer (Leco Corporation, St. Louis, MO) according to method 990.03 (AOAC,, 2007). Ethylenediaminetetracetic acid (EDTA) was used as the standard (9.56 ± 0.0 3 % N required; 9.51 ± .08 % N determined). A total starch kit (Megazyme K-TSTA, Wicklow, Ireland) was used to determine starch content in the feed samples according to a modified method 996.11 (AOAC, 2007). Titanium content in both the feed and feces was determined according to Leone (1973). All analyses were carried out in duplicate, except ADF which was done in triplicate. Analyses were repeated when the coefficient of variation (CV) for the duplicate samples exceeded 1%.

Apparent total tract digestibility of DM and energy was calculated according to Oresanya et al. (2007). Metabolizable energy was calculated according to Noblet and Perez (1993). Net energy was calculated according to the equation by Noblet et al. (1994): NE (Mcal/kg) = 0.700 x DE + 1.61 x ether extract + 0.48 x starch – 0.91 x %CP – 0.87 x ADF.

<u>Statistical Analysis.</u> All data were analyzed using the PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC) to evaluate normality. Data were analyzed using the PROC MIXED procedure. When individual model effects were significant sources of variation, separation was undertaken for each dependent variable, using the PDIFF option

in the MIXED procedure of SAS. For the nursery phase of the experiment, the model included the effects of feeder space treatment and sex. For the grow-finish period and for ATTD, the model included the fixed effects of feeder space treatment, diet treatment, and sex, and their 2-way interactions. Initial pig weight was used as a covariate for all models, which for the nursery phase was weaning weight and for the grow-finish phase was the weight at d 57 post-weaning. Model effects were considered significant sources of variation if $P < 0.05$ and trends if $P > 0.05$ and < 0.10.

Results and Discussion

No interactions ($P > 0.05$) were observed among the effects included in the models used to analyze the dependent variables from the present study; therefore, only treatment main effects will be reported.

Effect of Feeder Space Allowance on Nursery Pigs. Feeder space allowance did not affect BW, ADG, ADFI, or G:F ($P > 0.05$) overall (weaning to d 56 post-weaning; Table 2) or in any individual weigh period (Table 3). Our data are consistent with those reported by Wolter et al. (2002), where no performance differences were observed when pigs had access to 2 or 4 cm of feeder trough space per pig from weaning to wk 6 post-weaning. However, in the same study, from wk 6 to 8 post-weaning, pigs with access to 4 cm of trough space had a greater ADG, when compared to pigs provided 2 cm trough space. These findings at the end of the nursery phase differ from the findings in the present study. However, in that same study, Wolter et al. (2002) reported similar ADFI and gain:feed, which supports the present findings.

Overall for the nursery phase, there were no differences in ending BW, ADG, or G:F between the different genders (Table 2). However, ADFI tended to be greater ($P < 0.10$) in gilts when compared to barrows or in pens with both barrows and gilts (mixed sex pens).

Effect of Feeder Space Allowance and DDGS Inclusion on Grow-Finish Pigs. Overall, pig growth performance was not affected by feeder space allowance (Table 4); however, there was a trend for less feeder space to reduce market weight and ADG when expressed on a carcass weight, rather than live weight basis ($P < 0.10$). The degree of precision in this experiment was excellent, with SEM for ADG of only 8 g d^{-1}, for ADG when expressed on a carcass basis of only 60 and for ADFI of only 23 g d^{-1}. There are limited data in the scientific literature describing how growth performance is impacted by feeder space allowance and particularly at high DDGS inclusion levels. Our results agree with those of Gonyou and Lou (2000), who found no differences overall for ADG, ADFI, or G:F in a 12-wk study (25 to 106 kg) when pens of 12 pigs were offered either a single or multi-space feeders. Increased feeder space allowance did not improve gain or efficiency in a study reported by Morrow and Walker (1994), where pens of 20 pigs had access to either 1 or 2 identical feeders.

Turner et al. (2002) found that ADG was not significantly affected by offering pens of 20 or 80 pigs either 3.25 cm or 4.25 cm of feeder space over a 6-wk period from 29 to 56 kg. However, during the last three weeks (41 to 56 kg), ADG was significantly decreased when less feeding space was available. The results reported here are in agreement with Turner et al. (2002); during period 4 (96.1-122.6 kg), there was a linear decline in ADG ($P < 0.05$) and feed efficiency ($P < 0.01$) as feeder space declined. Wolter et al. (2003) reported when pigs were offered either 2 or 4 cm of feeder space per pig for 12 or 14 wks post-weaning (5.5 to 57 kg), no BW or ADG differences were observed. However, during the same study pigs provided 2 cm of feeder trough space per pig had decreased ADFI. Feed intake was not affected by feeder space allowance overall or from d 126 to market when both ADG and efficiency declined ($P > 0.05$). This result was surprising, as it was expected that all performance parameters would decline in late finishing.

Smith et al. (2004) concluded that feeders which provided the pigs with easier access to feed, including optimal feeder gap adjustment, reduce the time each pig spends eating, thus effectively increasing feeder utilization. In the present study, great care was exercised to ensure that at least one-third but no more than one-half of the feed trough was covered. Feeders were equipped with a crank system to ensure proper adjustment. This may explain the lack of ADFI response to feeder allowance because if feeders been adjusted more tightly, the response may have been different. Additionally, according to Brumm and Gonyou (2001), pigs will alter their typical eating patterns to adapt to their environment, including restricted feeder trough space. This adaptation could be another possible reason that ADFI did not decline as feed trough space declined in the present study.

Increased feeder competition and animal energy expenditure are possible explanations for the decline in gain ($P < 0.05$) and efficiency ($P < 0.10$) with no change in feed intake ($P > 0.10$) that was observed in the present study. Morrow and Walker (1994) reported that increased feeder waiting time may be related to increased animal activity. Spoolder et al. (1999) observed that competition for feeder access is more affected by feeder space availability per pig than the group size in the pen. Thus, when designing feeders, it is important to consider how both nursery and grower-finisher pigs will utilize the feeding space.

There were no final BW, ADG, ADFI, or efficiency differences across the entire grow-finish experiment due to DDGS treatment inclusion level ($P > 0.05$; Table 4). Various studies have reported no impact on ADG when feeding up to 30% DDGS (Cook et al., 2005, DeDecker et al., 2005, Gaines et al., 2007a). However, during both feed intake periods 1 and 3, pigs on the low DDGS diet had a greater ADFI when compared to the pigs fed the high DDGS diet ($P < 0.05$; Table 6). Xu et al. (2010) reported a linear decrease in ADFI for pigs fed diets containing 0, 10, 20 or 30% DDGS. This suggests that there could continue to be a linear decrease in ADFI as DDGS inclusion goes from 30 to 60%. We observed no differences during weigh periods 2, or 3 for ADG ($P > 0.05$). However, during weigh period 1 the pigs fed the D30 DDGS diet had increased ADG compared to the pigs on the D60 diet. Feeding DDGS at 30% inclusion rate can reduce ADG when compared to feeding none at all (Whitney et al., 2006).

Efficiency was improved for pigs on the D60 DDGS diet for periods 1 and 2 ($P < 0.05$), which may be attributed to the greater amount of choice white grease in this diet compared to the low DDGS diet treatment. DeDecker et al. (2005) found that inclusion of fat at 3 or 6% improved efficiency when fed with up to 30% DDGS, while at the same time decreasing ADFI. Thus, the inclusion of CWG at a higher level in the D60 DDGS diet compared to the D30 DDGS diet may explain the reduced ADFI for the pigs fed the high DDGS treatment for periods 1 and 3. On d 126 post-weaning, all pigs were put on a DDGS step down program (Table 1). During this time, pigs that were previously on the D60 DDGS diet had improved performance and had improved ADG and ADFI ($P < 0.05$) when compared to the pigs previously fed the D30 DDGS diet. Feed efficiency did not differ between pigs fed the two DDGS diets ($P > 0.05$). Pigs on the D60 diet needed to eat more feed to meet their energy need during this time and were better able to utilize the nutrients for gain than when they were previously eating the higher DDGS feed. This suggests that when the pigs were fed the 60% DDGS treatment they may have had greater gut fill and/or the fiber in the diet caused a greater feeling of fullness while they had a lower energy intake, due to the reduced ADFI during feed intake periods 1 and 3 of the grow-finish trial.

Carcass Characteristics. There were no feeder space allowance treatment differences for HCW, backfat depth, or loin muscle depth ($P > 0.05$; Table 6). Percent yield tended ($P < 0.10$) to linearly decline as feeder space allowance decreased. This difference was expected as there was a trend ($P < 0.10$) for market BW to decline with decreasing feeder space allowance. Additionally, there was a linear numerical decline in carcass weight as feeder space allowance was reduced. These two variables are directly related to percent yield, thus the decline was expected.

Pigs fed the D30 DDGS dietary treatment had a heavier HCW and greater percent yield by approximately 1% ($P < 0.05$; Table 7). Whitney et al. (2006) reported decreased carcass weight for pigs fed 20 or 30% DDGS compared to pigs fed 0 or 10% DDGS. Linneen et al. (2008) reported decreased carcass weight and dressing percentage for pigs as dietary DDGS increased from 0 to 30%. Cook et al. (2005) and Gaines et al. (2007a) reported decreased dressing percentage but no change in carcass weight in pigs fed diets that included between 0 and 30% DDGS. Due to percent yield differences between the 2 dietary treatments in the current study, feed efficiency was calculated on a carcass basis because intestinal fill could provide a greater proportion of overall BW due to the fiber content for the D60 DDGS diet treatment. Dried distillers grains with solubles have roughly 3 times more NDF than corn, and increased NDF in the diet from sources such as DDGS potentially leads to greater gut fill, as well as possible increased intestinal weight (Kennelly and Aherne, 1980; Pond et al., 1988). This theory is supported by Asmus et al. (2011) who found that pigs fed diets with 9.3% or 19.0% dietary NDF had increased full and stripped intestinal weights. In the current study, increasing DDGS concentration in the diet decreased loin depth ($P < 0.05$). However, there were no backfat depth differences resulting from the DDGS treatments ($P > 0.05$). The backfat and loin depth findings are supported by Whitney et al. (2006) and Gaines et al. (2007a) who reported similar results when including up to 30% DDGS in the diet.

Digestibility: There were no differences in DM and GE ATTD% or for dietary energy content of the diets for any of the 3 feeder space treatments or between sexes ($P > 0.10$). For both collection periods 1 and 2, when compared to pigs fed the D30 DDGS treatment had a greater ATTD for DM and GE ($P < 0.05$; Table 7) than pigs fed the high DDGS treatment. These data concur with Urriola and Stein (2010) who found that pigs fed a diet with 30% DDGS had a lower ATTD for DM and GE compared to pigs who ate a control corn-soybean meal diet. Widyaratne and Zijlstra (2007) reported greater total tract energy digestibility for pigs fed a wheat control diet compared to pigs fed diets which contained corn DDGS. Additionally, they reported greater DM excretion for pigs fed diets containing corn DDGS.

Stein et al. (2006) found that diets which contained DDGS had a lower ATTD for DM and GE than a corn-based diet. It is likely that reduced digestibility for the high DDGS dietary treatment in the current study was due to the increased fiber content (ADF and NDF). Dietary fibers such as ADF and NDF have a lower digestibility than starch when fed to pigs (Stein and Bohlke, 2007). Additionally, corn fiber utilization in growing pigs is primarily restricted by polysaccharide chemical composition and limited retention time in the hindgut.

Thus, fiber will become more available for digestion as the passage rate slows (Noblet and Le Goff, 2001).

For collection period 1, energy values (DE, ME, and NE) for the D30 DDGS diet were greater ($P < 0.05$; Table 8) than for the D60 DDGS diet. Stein et al. (2006) reported lower DE from pigs fed a diet containing 1 of 10 different DDGS sources compared to pigs fed a control corn-soybean meal diet, which supports the current findings. However, Pedersen et al. (2007) reported no difference in DE or ME values between a control diet with approximately 96% corn and diets containing 50% DDGS from 10 different DDGS sources. He did report DE and ME difference between DDGS sources though. The DE differences between the low vs. high dietary treatments could be related to the ADF, fat and starch content. As expected, the D30 DDGS diet in the current study had less ADF (4.65%) and more starch (30.75%) when compared with the D60 DDGS diet (7.56 and 14.72%, respectively); however, it also had lower fat content.

For collection period 2, energy content was greater ($P < 0.05$) for the D60 DDGS diet compared to the D30 DDGS diet. These results suggest that as pigs aged and BW increased, they were able to digest the dietary fiber more efficiently. A pig’s ability to digest dietary fiber increases with age and body weight (Noblet and Shi, 1993). Although not fully substantiated with data, Noblet and Le Goff (2001) suggested that hindgut size as a proportion of live weight or relative to feed intake increases with BW. This results in a slower digesta passage rate and prolonged time for fermentation in the ileum. Additionally, there could be possible changes in the microbial population composition found in the hindgut which could contribute to increased fiber digestibility (Noblet and Le Goff, 2001).

The analyzed ME values were less than the formulated values for the diets fed during collection period 1, but the values were greater for diets fed during collection period 2 (Table 2). For collection period 2, the calculated energy content of the diet was greater for the high DDGS treatment than the low (Table 7). The GE for the D60 DDGS diet was greater than for the D30 DDGS diet (4,793.95 and 4474.51 kcal/kg as fed respectively). Additionally, fat content of the D60 DDGS diet was greater than for the D30 DDGS diet (15.99 and 11.41% as fed, respectively). This suggests that the energy content of the DDGS was possibly underestimated during this period, and that the additional energy needed was overestimated.

Conclusions

Feeder space allowance did not impact BW or daily gain until pigs reached approximately 122 kg, but ADFI was not affected during any phase. Care has to be taken in applying these results to broader commercial conditions as factors such as feeder adjustment or greater ending BW could result in different performance outcomes. Gonyou and Lou (2000) suggested that diet form, feeder design, and BW range of pigs evaluated may impact feeder trough space allowance effects on pig performance. Therefore, more research is needed in this area. The high DDGS level did not decrease overall pig performance. However, when the DDGS level was reduced from 60% to 30% for the final phase, pigs on the high DDGS diet had a greater ADG and ADFI. The DM and energy digestibility was reduced during both collection periods for the pigs fed the high DDGS diet. This reduction is due to the higher amount of dietary fiber present in the diet.

Acknowledgements

Appreciation is expressed to Ag Feeds USA, LLC. for financial support of this experiment, and thanks are also expressed to Marc and Emily Melody, Whitney Holt, Zach McCracken, Theresa Johnson, Dr. Ron Kaptur, Dr. Chad Stahl, Dr. Buddy Hinson, and Eric Parr for their help and assistance.

Literature Cited

AOAC Int. 2007. Official Methods of Analysis. 18th rev. ed. AOAC Int., Gaithersburg, MD.

Asmus, M. D., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz, R. D. Goodband, and T.A. Houser. 2011. Effects of lowering dietary NDF levels prior to marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. Kansas State University Swine Day 2011. Report of Progress 1056:202-215.

Brumm, M. C., and H. W. Gonyou. 2001. Effects of facility design on behavior and feed and water intake. In: A.J. Lewis and L.L. Southern (ed.) Swine Nutrition, 2nd ed. Pp. 499-518. CRC Press, Boca Raton, Fl.

Cook, D., N. Paton, and M. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83 (Suppl. 1):335. (Abstr.)

DeDecker, J. M., M. Ellis, B. F. Wolter, J. Spencer, D. M. Webel, C. R. Bertlsen, and B. A. Peterson. 2005. Effects of dietary level of distiller's dried grains with solubles and fat on the growth performance of growing pigs. J. Anim. Sci. 83 (Suppl. 2):79. (Abstr.)

Gaines, A. M., G. I. Petersen, J. D. Spencer, and N. R. Augspurger. 2007a. Use of corn distillers dried grains with solubles (DDGS) in finishing pigs. J. Anim. Sci. 85(Suppl. 2):96. (Abstr.)

Gonyou, H. W., and Z. Lou. 2000. Effects of eating space and availability of water in feeders on productivity and eating behavior of grower/finisher pigs. J. Anim. Sci. 78:865-870.

Kennelly, J. J., and F. X. Aherne. 1980b. The effect of fiber addition to diets formulated to contain levels of energy and protein on growth and carcass quality of swine. Can. J Anim. Sci. 60: 385-393.

Leone, J. L. 1973. Collaborative study of the quantitative determination of titanium dioxide in cheese. J. AOAC. 56:535-537.

Linneen, S. K., J. M. DeRouchey, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J. L. Nelssen. 2008. Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579-1587.

Morrow, A. T. S., and N. Walker. 1994. Effects of number and siting of single-space feeders on performance and feeding-behavior of growing pigs. J. Agr. Sci. 122:465-470.

MWPS. 1991. Swine housing and equipment handbook. Midwest Service Plan MWPS-8, 4th ed., 3rd printing, Ames, IA.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

Noblet, J., and G. Le Goff. 2001. Effect of dietary fibre on the energy value of feeds for pigs. Anim. Feed. Sci. Tech. 90:35-52.

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.

Noblet, J., and X. S. Shi. 1993. Comparative digestibility of energy and nutrients in growing pigs fed ad-libitum and adults sows fed at maintenance. Livest. Prod. Sci. 34: 37-152.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Oresanya, T. F., A. D. Beaulieu, E. Beltranena, and J. F. Patience. 2007. The effect of dietary energy concentration and total lysine/digestible energy ratio on the growth performance of weaned pigs. Can. J. Anim. Sci. 87:45-55.

Pond, W. G., H. G. Jung, and V. H. Varel. 1988. Effect of dietary fiber on young-adult genetically lean, obese and contemporary pigs body weight, carcass measurements, organ weights, and digesta content. J. Anim. Sci 66:699-706.

Smith, L. F., A. D. Beaulieu, J. F. Patience, H. W. Gonyou, and R. D. Boyd. 2004. The impact of feeder adjustment and group size-floor space allowance on the performance of nursery pigs. J. Swine Health Prod. 12:111-118.

Spoolder, H. A. M., S. A. Edwards, and S. Corning. 1999. Effects of group size and feeder space allowance on welfare in finishing pigs. Anim. Sci. 69:481-489.

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 84:853-860.

Stein, H. H. and R. A. Bohlke. 2007. The effects of thermal treatment of field peas (*Pisum sativum L.*) on nutrient and energy digestibility of growing pigs. J. Anim. Sci. 81:2639-2645.

Stein, H. H., and G. C. Shurson. 2009. BOARD-INVITED REVIEW: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Turner, S. P., M. Dahlgren, D. S. Arey, and S. A. Edwards. 2002. Effect of social group size and initial live weight on feeder space requirement of growing pigs given food ad libitum. Anim. Sci. 75:75-83.

Urriola, P. E., and H. H. Stein. 2010. Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. J. Anim. Sci. 88:1454-1462.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Widyaratne, G. R., and R. T. Zijlstra. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 87:103-114.

Wolter, B. F., M. Ellis, B.P. Corrigan, J. M. DeDecker, S. E. Curtis, E. N. Parr, and D. M. Webel. 2003. Effect of restricted postweaning growth resulting from reduced floor and feeder-trough space on pig growth performance to slaughter weight in a wean-to-finish production system. J. Anim. Sci. 81:836-842.

Wolter, B. F., M. Ellis, S. E. Curtis, E. N. Parr, and A. M. Webel. 2002. Effects of feeder-trough space and variation in body weight within a pen of pigs on performance in a wean-to-finish production system. J. Anim. Sci. 80:2241-2246.

Xu, G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon, and G. C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower- finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-141.

1

Table 1. Ingredient inclusion, nutrient analysis, and energy content of dietary treatments fed during the late nursery and grow-finish phases.

	D30[1]					D60[1]				
Ingredient, %	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
Corn	39.9	41.4	45.5	50.8	58.4	37.6	14.55	20.1	25.5	54.9
Soybean meal, 47.5%	27.4	23.0	15.5	9.7	8.1	27.02	17.5	11.1	5.3	7.5
DDGS	27.5	30.0	32.5	32.5	26.3	30.00	59.9	59.9	59.9	30.0
Choice white grease	3.0	3.5	4.5	5.1	5.6	3.15	5.6	6.5	7.1	5.8
Limestone	1.1	1.1	1.1	1.1	1.0	1.09	1.5	1.5	1.5	1.0
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
l-Lysine HCl	0.44	0.40	0.37	0.30	0.28	0.44	0.41	0.36	0.29	0.28
l-Threonine	0.08	0.05	0.04	0.03	0.02	0.07	0.01	0.00	0.00	0.01
Methionine hydroxyl analog	0.12	0.07	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
Vitamin premix	0.10	0.10	0.10	0.10	0.07	0.10	0.10	0.10	0.10	0.07
Optiphos 2000	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Mintrex CU	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Iron oxide[2]						0.05	0.05	0.05	0.05	0.05
Analyzed values										
DM, %		89.6	90.0	90.0	88.5		89.3	88.8	89.7	88.8
GE, as-is, kcal/kg		4393.0	4410.9	4474.5	4387.0		4734.7	4660.9	4794.0	4449.9
Crude protein, as-is, %		21.8	20.4	17.1	15.5		25.7	23.6	21.5	16.3
Ether extract, as-is		9.1	9.8	11.4	10.9		14.4	13.3	16.0	11.2
ADF, as-is		5.0	4.7	5.1	4.2		7.2	7.6	7.4	4.8
Starch, as-is		27.8	30.8	32.9	38.8		12.1	14.7	18.1	38.9
Titanium dioxide, as-is			0.49	0.44				0.51	0.41	
Energy content, Mcal/kg[3]										
DE (analyzed)[4]			3.52	3.63				3.36	3.81	
ME (formulated)	3.38	3.40	3.44	3.48	3.52	3.38	3.40	3.44	3.48	3.52
ME (analyzed)[5]			3.36	3.50				3.18	3.63	
NE (analyzed)[6]			2.47	2.56				2.35	2.67	

[1]Treatment diet labels. Labeled by approximate amount of DDGS in the diet during phases 5, 6, and 7.

[2]Iron oxide was added to the D60 DDGS diet to differentiate it from the 30% feed to ensure delivery to the correct bin and feedline.

[3]Energy calculations only applied to diets which were fed during collection periods 1 and 2.

[4]Determined digestible energy concentration.

[5]Calculated using the equation by Noblet and Perez, 1993: ME (Mcal/kg) = DE x [1.003 - (0.0021 x %CP)].

[6]Calculated using the equation by Noblet et. al., 1994: NE (Mcal/kg) = 0.700 x DE + 1.61 x ether extract + 0.48 x starch - .091 x %CP - 0.87 x ADF.

Table 2. Overall nursery performance least squares means by feeder space and gender in a study investigating the effects of feeder space allowance on pig performance.[1]

	Feeder Space, cm/pig					Gender				
	2.1	2.5	2.9	SEM	*P*-value	Gilts	Barrows	Mixed [2]	SEM	*P* - value
No. of feeders	10	10	10			12	12	6		
No. of pigs/pen	62	62	62							
BW, kg										
d 0	5.7	5.7	5.7	0.035	0.94	5.6[b]	5.7[a]	5.7[a]	0.036	0.006
d 56	29.8	29.7	29.8	0.222	0.91	30.2	29.5	29.6	0.240	0.07
ADG, kg	0.48	0.47	0.48	0.005	0.95	0.48	0.47	0.47	0.005	0.25
ADFI, kg	0.69	0.70	0.68	0.008	0.41	0.71	0.67	0.69	0.009	0.05
G:F	0.69	0.68	0.70	0.008	0.27	0.69	0.70	0.68	0.009	0.24
Mortality, %	0.82	2.06	1.02	0.681	0.63	1.35	1.18	1.09	0.689	0.97
Morbidity, %[3]	1.68	2.28	3.56	0.349	0.35	2.01	2.43	2.78	0.350	0.79

[ab]Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Initial pig weight was used as a covariate in all models.

[2]Feeders had a pen of barrows on one side and a pen of gilts on the opposite side.

[3]Pigs which were removed from test due to illness or injury.

Table 3. Nursery performance least squares means by feeder space and gender in a study investigating the effects of feeder space allowance on pig performance.[1]

	Feeder Space, cm/pig					Gender				
	2.1	2.5	2.9	SEM	*P*-value	Gilts	Barrows	Mixed [2]	SEM	*P* - value
No. of feeders	10	10	10			12	12	6		
No. of pigs/pen	62	62	62							
Period 1										
Initial BW, kg	5.7	5.7	5.7	0.035	0.94	5.6^{b}	5.7^{a}	5.7^{a}	0.036	0.006
BW, kg	7.1	7.2	7.2	0.034	0.41	7.2	7.1	7.2	0.037	0.15
ADG, kg	0.24	0.25	0.25	0.006	0.48	0.26	0.24	0.25	0.006	0.33
ADFI, kg	0.21^{b}	0.23^{a}	0.21^{ab}	0.006	0.079	0.22	0.22	0.21	0.006	0.76
F:G	0.86	0.90	0.86	0.023	0.42	0.85	0.91	0.86	0.025	0.15
G:F	1.17	1.12	1.17	0.030	0.38	1.19	1.11	1.17	0.032	0.16
Period 2										
BW, kg	12.0	11.9	12.1	0.065	0.34	12.1	11.9	11.9	0.070	0.08
ADG, kg	0.35	0.37	0.38	0.015	0.45	0.39	0.35	0.36	0.016	0.14
ADFI, kg	0.47	0.46	0.47	0.007	0.91	0.47	0.46	0.46	0.007	0.35
G:F	0.75	0.80	0.81	0.028	0.27	0.81	0.76	0.79	0.031	0.49
Period 3										
BW, kg	17.8	17.5	17.5	0.146	0.40	18.2^{a}	17.2^{b}	17.3^{b}	0.160	0.0002
ADG, kg	0.44	0.42	0.41	0.009	0.22	0.46^{a}	0.40^{b}	0.41^{b}	0.009	0.001
ADFI, kg	0.59	0.60	0.58	0.009	0.25	0.62^{a}	0.56^{b}	0.59^{a}	0.010	0.0012
G:F	0.74	0.71	0.72	0.013	0.24	0.75	0.72	0.70	0.014	0.12
Period 4										
BW, kg	24.9	24.7	24.8	0.148	0.78	25.3^{a}	24.4^{b}	24.7^{ab}	0.162	0.002
ADG, kg	0.52	0.53	0.53	0.010	0.95	0.57	0.53	0.53	0.011	0.19
ADFI, kg	0.78	0.78	0.76	0.011	0.21	0.79	0.75	0.79	0.772	0.066
G:F	0.67	0.68	0.70	0.014	0.36	0.65^{b}	0.71^{a}	0.68^{ab}	0.016	0.017
Period 5										
BW, kg	29.8	29.7	29.8	0.222	0.91	30.2	29.4	29.6	0.240	0.07
ADG, kg	0.66	0.66	0.67	0.010	0.71	0.67	0.67	0.65	0.010	0.52
ADFI, kg	1.08	1.10	1.07	0.025	0.77	1.10	1.09	1.07	0.028	0.80
G:F	0.61	0.60	0.63	0.016	0.51	0.61	0.62	0.61	0.018	0.94

^{ab}Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Initial pig weight was used as a covariate in all models.

[2]Feeders had a pen of barrows on one side and a pen of gilts on the opposite side.

Table 4. Overall grow-finish performance least squares means by feeder space, diet, and gender in a study investigating the effects of feeder space allowance and dietary DDGS inclusion rate on pig performance.[1]

	Feeder Space, cm/pig					Diet				Gender				
	4.1	4.9	5.7	SEM	*P*-value	D30[2]	D60[2]	SEM	*P*-value	Gilt	Barrow	Mixed[3]	SEM	*P*-value
No. of feeders	10	10	10			15	15			12	12	6		
No. of pigs/pen	31	31	31			31	31							
BW, kg														
d 0	29.9	29.8	29.8	0.298	0.98	30.3[a]	29.3[b]	0.245	0.005	30.5[a]	29.1[b]	29.8[ab]	0.30	0.005
Market	121.5	122.2	122.9[a]	0.502	0.07	122.4	121.	0.451	0.41	121.7	122.3	122.4	0.55	0.68
CV, %														
d 61	18.3	17.9	17.2	0.731	0.57	18.0	17.6	0.649	0.72	17.6	17.7	18.1	0.79	0.90
d 152	11.1	11.0	9.8	0.552	0.21	10.9	10.5	0.327	0.59	10.9	9.9	11.1	0.60	0.34
ADG, kg	0.91	0.91	0.92	0.008	0.46	0.91	0.92	0.008	0.59	0.89[b]	0.94[a]	0.91[a]	0.00	0.001
ADG carcass, kg	0.69	0.70	0.71	0.006	0.08	0.71	0.69	0.005	0.07	0.67[b]	0.72[a]	0.70[ab]	0.00	0.01
ADFI, kg	2.06	2.04	2.04	0.023	0.83	2.07	2.03	0.021	0.21	1.98[b]	2.13[a]	2.05[b]	0.02	0.002
G:F[4]	0.44	0.45	0.45	0.005	0.34	0.44	0.45	0.005	0.11	0.45	0.44	0.44	0.00	0.81
G:F[5]	0.34	0.34	0.35	0.004	0.11	0.34	0.34	0.004	0.91	0.35	0.34	0.34	0.29	0.31
Days to Market	155.0	156.2	155.8	0.675	0.48	156.1	155.	0.605	0.40	158[b]	153[a]	156[ab]	0.74	0.002
Mortality, %	2.65	3.54	2.88	0.367	0.86	3.23	2.79	0.197	0.72	2.73	3.64	2.72	0.37	0.86
Morbidity, %[6]	2.59	2.27	3.07	0.276	0.68	2.85	2.41	0.233	0.63	3.24	2.90	1.92	0.27	0.46

[ab]Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Final pig weight was used as a covariate for all models.

[2]Treatment diet labels. Labeled by approximate amount of DDGS in the diet during phases 5, 6, and 7.

[3]Feeders had a pen of barrows on one side and a pen of gilts on the opposite side.

[4]Gain:feed calculated using live ADG.

[5]Gain:feed calculated using carcass ADG.

[6]Pigs which were removed from test due to illness or injury.

Table 5. Overall grow-finish performance least squares means by feeder space, diet, and gender in a study investigating the effects of feeder space allowance and dietary DDGS inclusion rate on pig performance.[1]

	Feeder Space, cm/pig					Diet				Gender				
	4.1	4.9	5.7	SEM	*P*-value	D30[2]	D60[2]	SEM	*P*-value	Gilt	Barrow	Mixed[3]	SEM	*P*-value
No. of feeders	10	10	10			15	15			12	12	6		
No. of pigs/pen	31	31	31											
Period 1[4]														
Initial BW,	29.9	29.8	29.8	0.298	0.98	30.3^{a}	29.3^{b}	0.245	0.005	30.5^{a}	29.1^{b}	29.8^{ab}	0.304	0.005
BW, kg	42.1	42.2	42.1	0.171	0.91	40.6^{b}	43.6^{a}	0.153	< .0001	42.3	42.1	41.9	0.190	0.40
ADG, kg	0.76	0.75	0.77	0.012	0.73	0.78	0.75	0.011	0.09	0.75	0.77	0.76	0.013	0.66
ADFI, kg	1.32	1.30	1.29	0.020	0.61	1.36^{a}	1.24^{b}	0.018	0.0003	1.32	1.31	1.28	0.022	0.25
G:F	0.58	0.58	0.60	0.007	0.18	0.57	0.60	0.007	0.006	0.57	0.59	0.59	0.008	0.23
Period 2														
BW, kg	73.4	73.8	74.1	0.310	0.40	74.3^{a}	73.3^{b}	0.278	0.023	73.2^{b}	74.7^{a}	73.5^{b}	0.341	0.014
ADG, kg	0.97	0.98	0.97	0.012	0.73	0.96	0.98	0.010	0.39	0.94^{b}	1.00^{a}	0.98^{a}	0.013	0.006
ADFI, kg	1.87	1.87	1.84	0.023	0.57	1.88	1.84	0.025	0.20	1.79^{b}	1.92^{a}	1.86^{ab}	0.027	0.006
G:F	0.52	0.52	0.53	0.006	0.28	0.51^{b}	0.53^{a}	0.005	0.016	0.52	0.52	0.53	0.006	0.92
Period 3														
BW, kg	95.9	96.1	96.6	0.443	0.55	97.0^{a}	95.5^{b}	0.400	0.021	94.9^{b}	98.1^{a}	95.6^{b}	0.493	0.0005
ADG, kg	1.07	1.05	1.07	0.014	0.57	1.07	1.06	0.012	0.32	1.04^{b}	1.11^{a}	1.05^{b}	0.015	0.004
ADFI, kg	2.41	2.37	2.39	0.037	0.67	2.45^{a}	2.34^{b}	0.033	0.03	2.27^{b}	2.53^{a}	2.38^{b}	0.040	0.001
G:F	0.44	0.45	0.45	0.005	0.50	0.44	0.45	0.004	0.062	0.46^{a}	0.44^{ab}	0.44^{b}	0.005	0.067
Period 4														
BW, kg	121.5^{b}	122.2^{ab}	122.9^{a}	0.502	0.07	122.4	121.9	0.451	0.41	121.7	122.3	122.4	0.553	0.68
ADG, kg	0.83^{b}	0.84^{ab}	0.88^{a}	0.012	0.02	0.82^{b}	0.88^{a}	0.011	0.002	0.84	0.86	0.85	0.013	0.44
ADFI, kg	2.44	2.41	2.44	0.029	0.73	2.36^{b}	2.50^{a}	0.017	0.002	2.31^{c}	2.54^{a}	2.44^{b}	0.032	0.0003
G:F	0.34	0.35	0.36	0.006	0.09	0.35	0.35	0.006	0.58	0.36^{a}	0.34^{b}	0.35^{ab}	0.007	0.11

[abc]Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Final pig weight was used as a covariate for all models.

[2]Treatment diet labels. Labeled by approximate amount of DDGS in the diet during phases 5, 6, and 7.

[3]Feeders had a pen of barrows on one side and a pen of gilts on the opposite side.

[4]Pigs on the 30% diet ate their phase budget 4 days faster than the pigs on the 60% diet.

Table 6. Carcass measurement least squares means by feeder space and diet in a study investigating the effect of feeder space allowance and dietary DDGS inclusion rate on carcass characteristics.[1]

	Feeder Space, cm/pig					Diet			
	4.1	4.9	5.7	SEM	*P*-value	D30[2]	D60[2]	SEM	*P*-value
No. of pens	10	10	10			15	15		
HCW, kg	92.7	93.4	93.8	0.292	0.06	93.9[a]	92.7[b]	0.246	0.004
Yield, %	75.2	75.7	76.1	0.237	0.06	76.1[a]	75.2[b]	0.200	0.005
Backfat depth, mm	12.8	12.7	12.8	0.550	0.98	12.6	12.9	0.463	0.60
Loin depth, mm	63.6	64.4	63.7	0.747	0.75	64.9[a]	62.9[b]	0.629	0.047

[ab]Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Final BW was used as covariate in all analyses.

[2]Treatment diet labels. Labeled by approximate amount of DDGS in the diet during phases 5, 6, and 7.

Table 7. Effect of feeder space allowance, dietary DDGS inclusion rate, and gender on the apparent total tract digestibility (ATTD) of DM and energy in a commercial environment.[1,2]

	Feeder Space, cm/pig					Diet				Gender				
	4.1	4.9	5.7	SEM	*P*-value	D30[3]	D60[3]	SEM	*P*-value	Gilt	Barrow	Mixed[4]	SEM	*P*-value
No. of feeders	5	5	5			5	5			12	12	6		
No. of pigs/pen	31	31	31											
d 92-94														
ATTD, %[5]														
Dry matter	74.3	74.9	75.0	0.274	0.18	79.8^{a}	69.7^{b}	0.269	< .0001	75.1	74.5	74.7	0.289	0.60
Gross energy	75.6	76.0	76.1	0.248	0.29	79.8^{a}	72.0^{b}	0.243	< .0001	76.1	75.5	76.1	0.261	0.15
Energy Content , Mcal/kg														
GE	4.69	4.69	4.70	0.009	0.96	4.70	4.69	0.009	0.39	4.70^{ab}	4.71^{a}	4.70^{b}	0.010	.026
DE[6]	3.42	3.44	3.45	0.011	0.31	3.52^{a}	3.36^{b}	0.011	< .0001	3.45	3.42	3.45	0.012	0.16
ME[7]	3.26	3.28	3.28	0.011	0.31	3.36^{a}	3.18^{b}	0.011	< .0001	3.28	3.25	3.28	4.000	0.16
NE[8]	2.40	2.41	2.42	0.008	0.32	2.47^{a}	2.35^{b}	0.008	< .0001	2.42	2.40	2.42	0.008	0.12
d 115-118														
ATTD, %[5]														
Dry Matter	79.6	79.0	79.5	0.311	0.37	81.2^{a}	77.5^{b}	0.296	< .0001	79.5	79.7	78.9	0.316	0.27
Gross energy	80.5	80.0	80.5	0.296	0.35	81.2^{a}	79.4^{b}	0.282	0.001	80.4	80.7	79.9	0.301	0.30
Energy Content, Mcal/kg														
GE	4.66	4.66	4.69	0.008	0.80	4.69^{a}	4.62^{b}	0.008	< .0001	4.67	4.65	4.65	0.009	0.21
DE[6]	3.73	3.71	3.73	0.014	0.35	3.63^{b}	3.81^{a}	0.013	< .0001	3.72	3.74	3.70	0.014	0.29
ME[7]	3.57	3.55	3.57	0.013	0.35	3.50^{b}	3.63^{a}	0.013	< .0001	3.57	3.58	3.55	0.013	0.29
NE[8]	2.62	2.61	2.62	0.010	0.35	2.56^{b}	2.67^{a}	0.009	< .0001	2.62	2.63	2.60	0.010	0.29

[ab]Within a row and main effect, means without a common superscript differ ($P < 0.05$).

[1]Fecal grab samples were collected from 1 pen per feeder for each dietary DDGS treatment for 2 consecutive days.

[2]Pig weight from the weigh period prior to collection period was used as a covariate for all models.

[3]Treatment diet labels. Labeled by approximate amount of DDGS in the diet during phases 5, 6, and 7.

[4]Feeders had a pen of barrows on one side and a pen of gilts on the opposite side.

[5]Calculated using the equation by Oresanya et al., 2007: DM or Nutrient ATTD Coefficient (%) =
100% - {[Diet Index Marker Concentration / Feces Index Marker Concentration) x (Feces Nutrient Concentration / Diet Nutrient Concentration

[6]Determined digestible energy concentration.

[7]Calculated using the equation by Noblet and Perez, 1993: ME (Mcal/kg) = DE x [1.003 - (0.0021 x %CP)].

[8]Calculated using the equation by Noblet et. al., 1994: NE (Mcal/kg) = 0.700 x DE + 1.61 x ether extract + 0.48 x starch - .091 x %CP - 0.87 x ADF.

Figure 1: Example of steel cover used to create the 2 feeder space treatments which had feeder spaces blocked. [1, 2, 3, 4]

[1]3 feeder space treatments 127 cm (4.1 cm/pig), 152.4 cm (4.9 cm/pig), and 177.8 cm (5.7 cm/pig) trough length.

[2]Feeder space treatments were created by blocking off 0, 1, or 2 feeder spaces. To make the smallest feeder trough length (127 cm) 2 spaces were covered (as shown above), for the 152.4 cm trough length 1 feeder space was covered, and for the 177.8 cm trough length no spaces were covered.

[3]Steel covers were manufactured by Iowa State Chemistry Machine Shop by bending the steel to cover the top and side of the feed spaces. Corners were rounded so no sharp edges were accessible by the pigs.

[4] Feeder utilized was a 7-hole Quick Adjust Style R, Smidley, Britt, IA

CHAPTER 3. GENERAL CONCLUSION

General Discussion

Understanding the effect of feeder space and inclusion of dried distillers grains with solubles in the diet on pig performance and total tract digestibility is important to maximize barn throughput and profit. Data presented in this thesis reported no difference overall for any performance variable when 3 different feeder space allowances were utilized in either the nursery or finishing phase. In the present study, gain and efficiency were reduced during approximately the last 30 days of the grow-finish trial (96 to 122 kg). During this same period, feed intake was not different between the treatments, confirming that the smallest feeder space was adequate. This suggests everyday management practices, such as feeder adjustments, play a role in maximizing feeder space allowance. Smith et al. (2004) concluded that feeders which provided the pigs with easier access to feed, including optimal feeder gap adjustment, reduces the time each pig spends eating, thus effectively increasing feeder utilization. Additionally, during this time there could have been more competition at the feeder or a longer wait time to access the feeder, thus increasing the pig's activity and energy expenditure, which resulted in reduced daily gain and decreased market BW for pigs on the smallest feeder space treatment.

Feeding a diet containing approximately 60% DDGS did not impact pig performance overall when fed with high dietary energy levels. Feeding diets containing relatively high DDGS inclusion levels did not cause gain or efficiency differences for the first 3 dietary phases of the trial. However, when the DDGS were reduced in the final phase (approximately last 30 days of the trial) from 60 to 30%, pigs on the high DDGS diet had a greater ADG and ADFI when compared to pigs from the low DDGS dietary treatment throughout the trial.

This could be an effect of less gut fill after each eating period due to the reduced fiber content. Dried distillers grains with solubles have approximately 3 times more NDF than corn, and increased dietary NDF from sources such as DDGS potentially leads to greater gut fill (Kennelly and Aherne, 1980; Pond et al., 1988), as well as possible increased intestinal weight.

There was no interaction of feeder space with DDGS inclusion level. This rejected one of our hypotheses which was that pigs fed diets which included approximately 60% DDGS would eat slower and thus need more feeder space. It has been speculated that when pigs are fed diets containing relatively large proportions of DDGS they will eat slower and visit the feeder more often. The eating slower and increased feeder visits by the pigs could be the result of greater gut fill as described earlier or decreased dietary palatability, although this is hard to measure. This could potentially alter feeder design and require producers to invest in new feeders, which would be expensive.

Corn DDGS contains mostly insoluble fiber, which is not readily fermented in the hindgut of the pig. The current data reported decreased DM and energy ATTD in the high DDGS diet during both collection periods. However, during collection period 2 the pigs utilized more energy and DM from the high DDGS diet than in collection period 1. This may be because as pigs get older, and the intestine becomes longer they are able to better digest fiber. Although not fully substantiated with data, Noblet and Le Goff (2001) suggested that hindgut size as a proportion of live weight or relative to feed intake increases with BW. This results in a slower digesta passage and prolonged time for digesta fermentation to occur in the ileum. Additionally, microbial population compositional changes in the hindgut could contribute to increased fiber digestibility (Noblet and Le Goff, 2001).

Recommendations for Future Research:

There is still a great deal of work to be done in the feeder space allowance and dietary DDGS inclusion levels area. Different feeder designs and space allowances need to be examined closely, as these may affect pig performance to a greater or lesser extent than the present study particularly, as market weights are expected to increase in coming years. Varying feeder space allowances under different environmental conditions (i.e. hot or cold barn temperature) is another possible area for research as having more than one environmental stressor may have a greater impact than just feeder space alone. Trials still need to be done feeding diets with high DDGS levels that do not include added energy. This would allow us to understand if pigs could eat 60% DDGS and still have no reduction in gain compared to those who eat lower levels. Digestibility work on these diets with no added fat would be useful as well to see if pigs really do become better fiber digesters as they age.

Literature Cited

Kennelly, J. J., and F. X. Aherne. 1980b. The effect of fiber addition to diets formulated to contain levels of energy and protein on growth and carcass quality of swine. Can. J. Anim. Sci. 60:385-393.

Noblet, J., and G. Le Goff. 2001. Effect of dietary fibre on the energy value of feeds for pigs. Anim. Feed. Sci. Tech. 90:35-52.

Pond, W. G., H. G. Jung, and V. H. Varel. 1988. Effect of dietary fiber on young-adult genetically lean, obese and contemporary pigs body weight, carcass measurements, organ weights, and digesta content. J. Anim. Sci. 66:699-706.

Smith, L. F., A. D. Beaulieu, J. F. Patience, H. W. Gonyou, and R. D. Boyd. 2004. The impact of feeder adjustment and group size-floor space allowance on the performance of nursery pigs. J 12:111-118.

APPENDIX

Gestal XM® Feed Delivery System

There are a variety of feed delivery systems available for use in swine barns. Each system has been tested and has its strengths and weaknesses. For the current study, feed delivery was recorded using Gestal XM® technology (Figure 2; Jyga Technologies, Quebec, Canada). This is a volumetric system, run by a motor rotating every 15 minutes to dispense feed into the feeder. The delivery is recorded through a wireless antenna system to a computer with the associated software installed on it. Feed delivery was updated every 15 minutes and the daily total was displayed on the computer screen (Figure 3). The daily total was reset to zero at midnight daily. The system was calibrated weekly and at dietary phase changes. Additionally, accuracy was estimated on each Gestal 2 different times during the trial. To check Gestal accuracy, they were paused the night prior to vacuuming and feed weigh back, so there would be no feed delivered from 12 am until the Gestal was re-started once remaining feed was emptied from each feeder. Once the feeder was empty the Gestal was re-started and feed delivery started again. The Gestal would complete 4 feed cycles and then would be paused again so no additional feed would be delivered to the feeder. Feeders were vacuumed and feed weighed to determine the difference between actual and recorded deliveries. All feed data from the computer was multiplied by the delivery error for the respective feeder, 8.3% for the D30 DDGS diet treatment and 9.9% for the D60 DDGS diet. The multiplied number was then subtracted from the original feed data, which gave the actual feed which was delivered. The actual feed number was used in all feed intake and efficiency calculations.

Using the PROC MIXED procedure of SAS (SAS Institute, Cary, North Carolina), the delivery error for each diet was determined. The model included diet, replicate, and phase. The interactions of diet and rep, diet and phase, and rep and phase were all analyzed. None of the interactions were significant. Feeder within diet was considered the random variable. A correction factor was determined for both the low and high DDGS diets, using a model which included data from the feeders which were tested during phases 6 and 7. The correction factors and the reason for this model in explained in greater detail below.

Using any type of volumetric feed delivery system will have some level of error associated with the amount of feed that is said to be delivered, particularly when feeding diets that substantially differ in fiber content. Because this error is known to exist, it is important to establish the magnitude of the difference between the predicted and actual weight of feed that is delivered by feed treatments. In this case we were dealing with only 2 diets that differed in DDGS inclusion rate. Hence, the difference between predicted and actual feed weight delivered was determined for both dietary treatments. The error associated with Gestal XM® delivery system was determined by calculating the percent error during phases 6 and 7. This model was used because during these two phases, a 30% and 60% diet was being fed. This gave us the most precise estimate of the true error of the system when feeding high fiber diets. The error for the 2 diets was 8.3 and 9.9% (Table 1) for the 30 and 60% DDGS inclusion levels, respectively. For phase 8, where the DDGS inclusion rate for the two diets was 27.5 and 30%, all feed delivery data was corrected using the correction that was calculated from the 30% DDGS diet. There was no difference between dietary phase and the time when the delivery accuracy was checked.

Table 1. Least square means for the effect of diet on Gestal XM® delivery error.

	Diet				Rep[2]				Phase[3]			
	D30[1]	D60[1]	SEM	*P*-value	1	2	SEM	*P*-value	6	7	SEM	*P*-value
Error, %	8.3	9.9	1.49	0.30	8.6	9.6	1.55	0.70	9.8	8.4	1.61	0.58

[2]Each feeder was vacuumed and feed weighed 2 separate times.

[3]Dietary phase of an 8-phase feeding program.

Figure 2: Gestal feed delivery system.

Figure 3: Gestal feed delivery display screen.